Final Report for Period: 10/2010 - 09/2011 **Submitted on:** 11/07/2011
Principal Investigator: Weinberg, Gil . **Award ID:** 0713269
Organization: Georgia Tech Research Corp
Submitted By:
Weinberg, Gil - Principal Investigator
Title:
HRI: The Robotic Musician - Facilitating Novel Musical Experiences and Outcomes through Human Robot Interaction

Project Participants

Senior Personnel

Name: Weinberg, Gil
Worked for more than 160 Hours: Yes
Contribution to Project:

Post-doc

Name: Hoffman, Guy
Worked for more than 160 Hours: Yes
Contribution to Project:
Developed a new control system for the robotic musician, composed an interactive piece for it and played with the robot in a concert.

Graduate Student

Name: Blosser, Brian
Worked for more than 160 Hours: Yes
Contribution to Project:
Developed an implementation for a leader-follower module based on beat detection for human- robot interaction.

Name: Mallikarjuna, Trishul
Worked for more than 160 Hours: Yes
Contribution to Project:
Developed an improvisation module based on hidden markov model for the robotic musician

Name: Nikolaidis, Ryan
Worked for more than 160 Hours: Yes
Contribution to Project:
Developed a learning system that the robotic musician uses for improvisation

Undergraduate Student

Technician, Programmer

Other Participant

Research Experience for Undergraduates

Organizational Partners

Alium Labs LLC

Alium Labs designed a 4-arm robotic mechanism that can address the musical needs of the project.

The company has built the4-arm robot, shipped it to Georgia Tech and installed it in location. It also designed a social robotic head for the robot.

Gibson Engineering Company

Gibson Engineering manufactured the robotic arms for the project.

Other Collaborators or Contacts

Karan Mehar and Aparna Raman, graduate students at Georgia Tech, developed the animation for the social robotic head. The students developed these applications as part of class projects and were not funded by this award.

Activities and Findings

Research and Education Activities:

Hardware - Four robotic arms were developed, each actuated by a voice-coil linear actuator, and running along the same rail, in parallel to the marimba's long side. The linear actuators are based on a commercial product by IAI and are controlled by a SCON trajectory controller. The arms are custom-made aluminum shells hosting two rotational solenoids each. The solenoids control the mallets, chosen with an appropriate softness to the area of the marimba that they are most likely to hit. Each arm contains one mallet for the bottom-row (?white') keys, and one for the top-row (?black') keys. A social robotic head has been added to the robot in an effort to enhance the notion of embodiment and visual cues.

Software - Four interaction modules have been developed for the robot, exploring different approaches for machine-musicianship. For the first module we developed computational models of musical percepts such as similarity, stability, and tension, which were used to drive a novel genetic algorithm improvisation engine (1). The second module was based on a newly developed beat detection algorithm that utilized a high-level model for leader-follower rhythmic interaction (2). The third module utilized Hidden Markov Model analysis of human musical input, used by Shimon to respond in a similar style (3). The fourth module was developed based on the notion of choreographic gestures and anticipation, combining physical movement patterns with musical perception, and anticipatory movement for better synchronization (4).

User studies have been conducted that evaluates the role of visual cues and embodiment in human-to-human interaction as well as human-to-robot interaction.

Concerts with the robot have been conducted where students developed new applications, composed for and played with the robot

Findings:

Hardware - we learned that the combination of 8 rotary solenoids, 2 per arm, moving along a 6 fit slider provides the most effective balance between speed, sound quality, path planning and anthropomorphic design.

Software - In an informal user survey based on the interaction modules, listeners found the outcome compelling and musical. Wired.com titled its article about the project: 'Robots

Pass Musical Turing Test'. (http://www.wired.com/listening_post/2008/11/no-way-robot-ja/. More formal user studies will be conducted in the spring.

The user studies that were conducted and published strengthened the hypothesis that the physicality of the robotic musician improved synchronization, anticipation and coordination with human co-players. we tested the effects of visual contact and embodiment on audience appreciation. We find that visual contact in joint Jazz improvisation makes for a performance in which audiences rate the robot as playing better, more like a human, as more responsive, and as more inspired by the human. They also rate the duo as better synchronized, more coherent, communicating, and coordinated; and the human as more inspired and more responsive

Training and Development:

A syllabus for a hands-on research class were designed by the P.I for the project. The class ended in a public concert of students' projects where two pieces for the robot were performed. (2009 - http://gtcmt.coa.gatech.edu/?p=1623, 2010 - http://www.coa.gatech.edu/news/event.php?id=5428)

Research skills and experiences:
Students learned to define research goals, set up a programming environment to address the research goals, work collaboratively towards a public presentation of their projects and assess their efforts. Students also learned how to write papers about their work (published as conference proceedings and Journal papers).

Outreach Activities:

A concert based on a genetic-algorithm improvisation engine was selected and performed in Copenhagen Denmark as part of the International Computer Music Conference.

A presentation of the animated robotic head as it responds to musical input was presented in a number of public settings in Atlanta.

The robot was presented at the launch of the new Georgia Tech Center for Music Technology. The launch received wide coverage: http://gtcmt.coa.gatech.edu/?page_id=15

A concert in Atlanta was performed with two composition for the robot. (2009 http://gtcmt.coa.gatech.edu/?p=1623) (2010 - http://www.coa.gatech.edu/news/event.php?id=5428)

Workshops and concerts for children with the robot at the US Science Fair in Washington D.C

Concerts and workshop of the robot at the Bumbershoot festival in Seattle

Concerts and workshop of the robot at the DLD conference in Germany

The robot also performed in the international Digital Design Life in Germany - http://www.dld-conference.com/

Stories about the robot have been published in CNN, NPR (All Things Considered), and Colbert Report

More Youtube clips were posted and widely viewed (more than 150,000 views combined).
See for
example:
http://www.youtube.com/watch?v=jqcoDECGde8, http://www.youtube.com/watch?
v=5DYOqSTmGDA, http://www.youtube.com/watch?v=gm9R05PMHDM)

Journal Publications

Weinberg G., Godfrey M., Rea, A., Rhodes, J., "A Real-Time Genetic Algorithm In Human-Robot Musical Improvisation", Lecture Notes in Computer Science, p. 351, vol. 4969, (2008). Published,

Weinberg, G; Driscoll, S, "Toward robotic musicianship", COMPUTER MUSIC JOURNAL, p. 28, vol. 30, (2006). Published,

Hoffman, G; Weinberg, G, "Interactive improvisation with a robotic marimba player", AUTONOMOUS ROBOTS, p. 133, vol. 31, (2011). Published, 10.1007/s10514-011-9237-

Books or Other One-time Publications

Weinberg, G., "Human-Robot Interaction", (2007). Book, Published
Editor(s): Sarkar N
Bibliography: ISBN 978-3-902613-13-4,

Weinberg, G., Blosser B., Mallikarjuna,
T., Ramen, "Human-Robot Interactive Music in the
Context of a Live Jam Session", (2009). Conference Proceedings, Published
Bibliography: In the Proceedings of International
Conference on New Instruments for
Music Expression (NIME 09),
Pittsburgh, PA, pp. 70-73.

Weinberg, G., Blosser B., "A Leader-Follower Turn-taking Model
Incorporating Beat Detection in Musical
Human-Robot Interaction", (2009). Conference Proceedings, Published
Bibliography: In the Proceedings of the ACM/IEEE
International Conference on Human
Robot Interaction, (HRI 2009) San
Diego, CA.

Weinberg, G., Mallikarjuna, T., Ramen, "Interactive Jamming with Shimon: A
Social Robotic Musician", (2009). Conference Proceedings, Published
Bibliography: n the Proceedings of the ACM/IEEE
International Conference on Human
Robot Interaction, (HRI 2009) San
Diego, CA, pp. 233-234.

Weinberg, G., Hoffman G., "nteractive Improvisation with a Robotic
Marimba Player", (2010). Book Chapter, Published
Editor(s): ?, Solis, J. and Ng K
Collection: Musical Robots and Interactive
Multimodal Systems
Bibliography: New York: Springer Press

Web/Internet Site

URL(s):

http://gtcmt.coa.gatech.edu/?p=628

Description:

A general website for the project presenting all the latest developments, videos, papers etc.

Other Specific Products

Product Type:

Concert

Product Description:

An interactive composition for the robotic musician was selected and performed by the International Computer Music Conference, Copenhagen, Denmark, August 31 2007.

Sharing Information:

The concert was published, reviewed and attended.

Product Type:

Exhibition

Product Description:

An exhibition of social-musical interaction with an animated robotic head as part of the listening Machines concert series.

Sharing Information:

http://lm.gatech.edu (see Simon Listens at the bottom of the page)

Product Type:

Concert

Product Description:

A public concert featuring the Robotic Marimba Player - http://gtcmt.coa.gatech.edu/?p=1623, http://www.coa.gatech.edu/news/event.php?id=5428

Sharing Information:

The concert was widely advertised in Atlanta and nationally. It received wide coverage in blogs such as Gizmodo (http://gizmodo.com/5228375/shimon-robot-takes-over-jazz-as-doomsday-gets-a-bit-more-musical) and Engadget (http://www.engadget.com/2009/04/26/video-robotic-marimba-player-grooves-autonomously-with-jazz-pia/)

Product Type:

Audio or video products

Product Description:

A new Youtube clip presenting Shimon interacting with human.

Sharing Information:

The clip has been presented by NPR, The Colbert Report and other media outlets and has been viewed by over 30,000 viewers

Product Type:

Audio or video products

Product Description:

Georgia Tech's PSA

Sharing Information:

http://www.gatech.edu/music/robotics.html

Product Type:

Best Paper Award in ICRA 2010

Product Description:

Hoffman, G. and Weinberg, G. (2010), ?Gesture-based Human-Robot Jazz Improvisation?, Proceedings of the IEEE International Conference on Robotics and Automation (ICRA 10), Anchorage, AK, USA,

Sharing Information:

The paper received best cognitive paper award

Product Type:

Presentation

Product Description:

World Economic Forum, TEDx

Sharing Information:

The project was invited to be presented in exclusive venues such as the World Economic Forum in Davos and TEDx

Contributions

Contributions within Discipline:

In the field of Human-Robot Interaction, the project is one of the firsts to facilitate human-robot collaboration for musical, non utilitarian, goals. The techniques we developed for robotic arm, head, and eye movements to represent musical percepts and moods can help create social and emotional communication between humans and robots, leading to more expressive and intuitive human-robot interaction.

The user studies conducted are the first to explore the role of embodiment and visual communication in human-robot interaction.

Contributions to Other Disciplines:

In the field of computer music, the project is one of the firsts (if not THE first) to combine music perception and improvisation modeling with robotic actions. The techniques we developed for arm actuation can shed light on the physical balances required for virtuosic playing. Our approach for analyzing beat detection and melodic tension can help explain how humans perceive music and what leads to our enjoyment of music. The genetic algorithm improvisation engine we developed has led to novel musical outcomes that are the combination of generative algorithms and human input. The hidden markov model, leader-follower interaction and the focus on gestures for synchronization and anticipation has been referred to as novel and exciting. In some publications such as Wired the robot was described as 'passing the turing test.'

Contributions to Human Resource Development:

The students and collaborators who worked on the project developed their scientific and engineering skills along with their musical and artistic skills. Such whole -rounded education can lead to better problem solving skills and out-of the box thinking, which can contribute to human resource development in science, engineering and technology.

The project was one of the main research projects at the newly developed Georgia Tech Center for Music Technology which currently has 20 faculty members involved. The media exposure of the project also helped in students recruiting for the MS in Music Technology,

which currently has 15 new graduate students.

Building on the success of this (and other projects), the Georgia Tech Center of Music Technology has been approved to offer a PhD program starting Fall of 2010.

Contributions to Resources for Research and Education:

The NSF grant lead to an additional Georgia Tech grant (namely GVU seed grant), in collaboration with Dr. Andrea Thomaz from the College of Computing at Georgia Tech. Dr. Thomaz's research focuses on social interaction between humans and robots, and we plan to combine her research on facial expression in the perceptual robotic musician. This project is part of the new Robotic Intelligence Machines Center at Georgia Tech, and can help position it as a unique interdisciplinary center.

The project was presented in a full house concert in Atlanta titled 'Listening Machines' - http://gtcmt.coa.gatech.edu/?p=1623

The project also helped the establishment of the new Georgia Tech Center for Music Technology - a cross campus interdisciplinary research center directed by the P.I - http://gtcmt.coa.gatech.edu/?page_id=11

Georgia Tech has used the robot in its Public Service Announcement, using the project to define what Georgia Tech would like to be about - http://www.gatech.edu/music/robotics.html

Contributions Beyond Science and Engineering:

The preliminary outcome of the project (book chapters, journal papers, conference papers, public concerts, and an artistic installation) brought a unique artistic approach for human-robot interaction into the public eye. The importance of federal support for scientific research into art and music has been examined in public settings.

The project was invited to be presented at the World Economic Forum in Davos as part of a session called 'Robo-Spaience', where world leaders where introduced to new ground breaking developments in robotics.

Conference Proceedings

Weinberg, G;Godfrey, M;Rae, A;Rhoads, J, A real-time genetic algorithm in human-robot musical improvisation, "AUG 27-31, 2007", COMPUTER MUSIC MODELING AND RETRIEVAL: SENSE OF SOUNDS, 4969: 351-359 2008

Weinberg, G;Driscoll, S, The design of a perceptual and improvisational robotic marimba player, "AUG 26-29, 2007", 2007 RO-MAN: 16TH IEEE INTERNATIONAL SYMPOSIUM ON ROBOT AND HUMAN INTERACTIVE COMMUNICATION, VOLS 1-3, : 764-769 2007

Weinberg, G;Driscoll, S;Parry, M, Musical interactions with a perceptual robotic percussionist, "AUG 13-15, 2005", 2005 IEEE INTERNATIONAL WORKSHOP ON ROBOT AND HUMAN INTERACTIVE COMMUNICATION (RO-MAN), : 456-461 2005

Hoffman, G;Weinberg, G, Gesture-based Human-Robot Jazz Improvisation, "MAY 03-08, 2010", 2010 IEEE INTERNATIONAL CONFERENCE ON ROBOTICS AND AUTOMATION (ICRA), : 582-587 2010

Categories for which nothing is reported:

Hoffman, G., Weinberg, G. (2010) “Shimon: An Interactive Improvisational Robotic Marimba Player," Extended Abstracts Proceedings of International ACM Computer Human Interaction Conference (CHI 10), Atlanta, GA.

Weinberg, G., Hoffman, G. Nikolaidis, Ryan, Aimi, R (2009) “Shimon and ZOOZbeat: an Improvising Robot Musician You Can Jam With.” Extended Abstract Proceedings of ACM SIGGRAPH Asia, Yokohama, Japan, p. 84

Hoffman, G. and Weinberg, G. (2010) "Gesture-based Human-Robot Jazz Improvisation", Proceedings of the 2010 IEEE International Conference on Robotics and Automation (ICRA 10), Anchorage, AK. **(Awarded Best Cognitive Paper)**

Hoffman, G., Weinberg, G. (2010) "Interactive Improvisation with a Robotic Marimba Player", to be published in ", Solis, J. and Ng K., (Eds.) Musical Robots and Interactive Multimodal Systems, New York: Springer Press.